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DESIGN EVALUATION FOR PERSONNEL, TRAINING, AND HUMAN FACTORS (DEPTH)

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This paper describes a new direction in human factors research called Design Evaluation for Personnel, Training, and Human Factors (DEPTH). This research utilizes computer-aided design (CAD) man-modeling and data base technologies to foster a human-centered approach to weapon system design. The ability to graphically simulate maintenance work underlies this research. Visualizing maintenance tasks will allow more accurate and complete descriptions of human performance requirements during design. This man-modeling capability will utilize a computer graphic workstation capable of importing CAD data and will build upon technology developments of CREW CHIEF, a model of a maintenance technician developed by Air Force Human Resources Laboratory (AFHRL) and Armstrong Aerospace Medical Research Laboratory (AAMRL). Additional capabilities include detailed hand and vision models, multi-person task performance simulation, the effects of environmental, and animated simulations of complete maintenance tasks. Logistics Support Analysis (LSA), training, and personnel information will be derived from these simulations and presented in a usable format.

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PREFACE

The information presented in this paper was developed from a new research and development project designed to allow human factors, personnel, and training information to be obtained through computer graphics weapons system design. A condensed version of this paper appeared in the magazine High Performance Systems (April 1990).

SUMMARY

Design Evaluation for Personnel, Training, and Human Factors (DEPTH) is a new direction in the use of computer graphics man-modeling. The concept is to use existing computer-aided design (CAD) man-model technology and incorporate information relevant to Logistics Support Analysis (LSA), personnel, and training. Through simulations on CAD designs, the DEPTH user will be able to determine human factors and human resource requirements with respect to maintainability. These simulations are also expected to make such analyses easier and more accurate than current methods. The software will be housed in a computer graphic workstation and will be able to import CAD data. Designs can be displayed with surfaced images in three-dimensional space and will be capable of real-time manipulation. The program will "understand" how to construct maintenance tasks when given high-level commands from the user. Animation will be used to display results. Crew Chief, a man-model developed by the Air Force Human Resources Laboratory (AFHRL) and the Armstrong Aerospace Medical Research Laboratory (AAMRL), will be the baseline for the ergonomics capabilities within DEPTH.

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I. INTRODUCTION

This paper describes a research agenda for improving human-centered design evaluation and resource planning in modern computer-aided design (CAD) environments. Improvements will be housed in a computer graphics workstation supporting analyses in several domains. The emphasis will be on the expansion of human man-modeling capabilities. This man-model will allow human/machine integration to be simulated and provide design aids to the user. Therefore, the the need for costly physical mock-ups is significantly reduced. Additionally, this technology may be used to determine task and job ability requirements and to produce accurate information for instructional development and training media.

II. THE PRESENT

In the past decade, significant advances in computer graphics technology have made it possible to simulate human/machine interaction during weapon system design. To date, man-modeling has focused principally on the physical limitations of humans to do work. That is, for proposed equipment or workplace layouts, the objective is to find out if a human can: fit into, reach, see, and move man-made objects. Most models provide a three-dimensional simulation of human activities. Some have an accurate anthropometric data base to create realistic human activity simulations.[1] Figure 1, for example, shows a video display created by Crew Chief, a widely distributed man-model developed by the Air Force Human Resources Laboratory (AFHRL) and Armstrong Aerospace Medical Research Laboratory (AAMRL).[2]

Man-models such as Crew Chief allow evaluation of equipment and workplace before before anything is actually built. They diminish the need for physical mock-ups and prototypes which have traditionally been

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[1] For reviews and comparisons of man-models, see Kroemer, Snook, Meadows, and Deutsch (1989), and Hickey and Pierrynowski (1985).

[2] See Easterly (1989) for details on Crew Chief.

needed for these analyses. With these tools, ergonomics can be taken into account earlier in the acquisition process. When a problem is discovered, changes can be made relatively fast and much less costly.

Simulations of aircraft and automobile operators have traditionally been the primary function of computer man-models. However it is becoming increasingly popular to use these models for maintenance evaluation.[3] A number of computer-aided engineering (CAE) techniques

DESIGN TORQUE LIMITS
FOR TOOL ANALYSIS
PREDICTED TORQUE

PERCENTILES	TORQUE IN FT-LBS	
	TIGHTEN	LOOSEN
1st	23.62	26.46
5th	28.10	33.69
50th	38.41	50.78
95th	62.22	70.81
99th	58.69	79.99

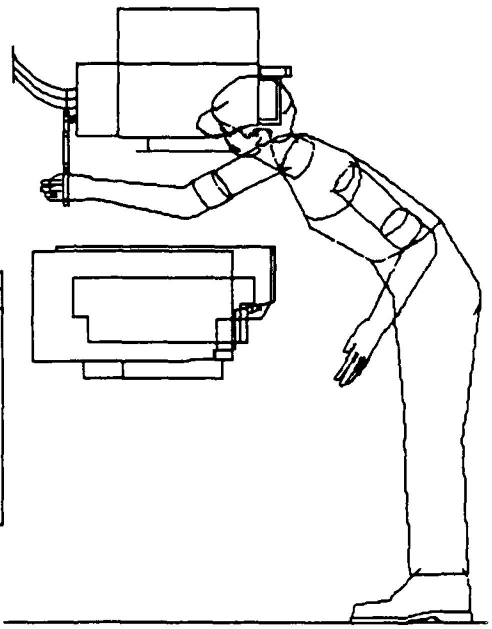

Figure 1. Crew Chief Video Display

aimed at pilot-operator simulation are also being developed. Evolving computer technology is providing new opportunities to enhance the reach of design evaluation. We may now begin to expand human factors analyses and incorporate personnel and training factors while building on

[3]See Elkind et al. (1989) for a description of new "computational" human factors work. See reviews by Rothwell (1985), Richards and Companion (1982), and Hidson, D. (1988).

and improving current man-modeling methods for human/machine integration.

III. THE FUTURE

The research proposed in this concept paper will develop new methods for describing and evaluating maintenance support requirements during the design process. This technology will help identify design deficiencies from a maintainer's standpoint. Workstation animation will accurately simulate interactions between human and machine. The software system will import three-dimensional CAD data and have access to maintenance and human performance data bases, as shown in Figure 2. Mechanisms for design influence and human factors documentation will be created through this integration. While these human factors analyses are taking place, Logistics Support Analysis Record (LSAR) data bases may be updated.[4]

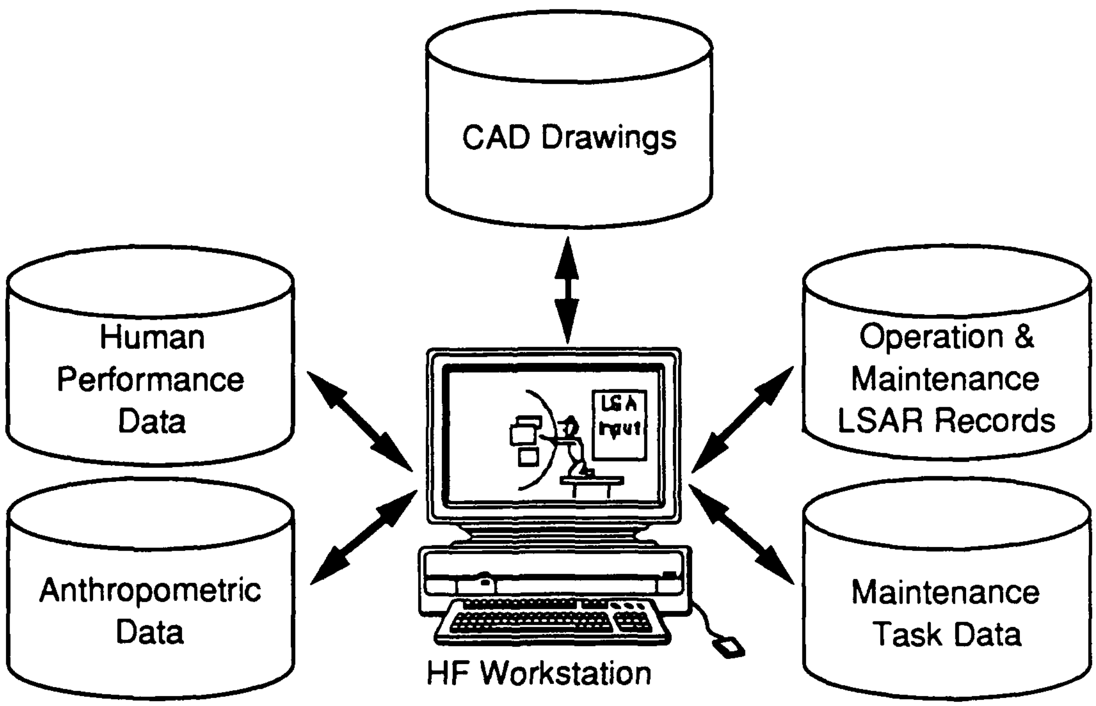

Figure 2. Advanced Man-modeling Concept

[4]LSAR is the Department of Defense's method for insuring supportability and other logistics elements are tracked throughout the acquisition of a weapon system.

Task analysis information produced from these simulations has two functions. First, it will help to constrain (or improve) equipment design for human factors. Second, it will provide accurate task documentation for LSAR data records to support human resources and other logistics planning functions.

Maintenance task analyses implemented in this CAD-graphics context will help to define human ability requirements in physical, perceptual, psychomotor, and cognitive domains. Task performance requirements within these four domains will be estimated by combining computer graphic task simulations. For example, non-graphic information applicable to the simulated task will also be provided to aid the task analyst. This strategy will allow human performance limitations (or capabilities) that degrade (or enhance) system performance for given design options to be more readily identified and more easily accommodated during design development than they are now. Incorporation of design prescriptive information and criteria will help users improve a design concept from a human factors (HF) point of view. Integration with CAD will assure that human performance problems identified by these rapid-prototyping HF methods will be passed back to equipment designers for resolution. Integration with LSAR operation and maintenance task data (records C & D) will provide a coherent data stream for equipment support analysis for human resources.

IV. RESEARCH GOALS

Enhance Capabilities of Existing Man-Models

The first objective is to enhance current man-modeling software with new capabilities and an improved user interface. Real-time animation and automatic task composition are at the root of these new capabilities. Other ergonomic related developments will include: automation of task performance, a detailed hand model, effects of environmental conditions, enhanced vision model, and simulation of multi-person tasks.

Automatic task composition. Current models require the user to specify basic movements of the man-model. These models are good for detecting isolated maintenance problems but they are too time consuming for more complete tasks. Crew Chief, for example, is able to reach for a bolt with realistic body positioning, but if there are several bolts attached to a component, the user must input information over again for each bolt. This is a very tedious task for the user because he must wait for the program to reach for each bolt.

Automatic task composition, on the other hand, will require less input of higher level information. To remove a component the user will not need to guide every action required to perform the task. With CAD item libraries, it should be possible for the model to find the location of all fasteners and remove these before the component can be lifted out. After the computer determines what needs to be done, the activity will be displayed using real-time animation. Without this capability, the other proposed analyses will be difficult or impossible to implement.

Detailed hand model. Since most maintenance work is accomplished with the hand, a detailed hand model is needed. Data on human hand limitations is available and at least one computer model has been developed.[5] The hand model will be available to the DEPTH user when more detail analysis is needed.

Vision. Detailed vision models are also being developed at several locations. Crew Chief has a limited vision model which does not sufficiently display the effects of obstacles and lighting. The vision model will use data from Crew Chief and augment it with data from other sources. For example, the Crew Chief vision model does not account for effects of lighting. This limitation was posed not by the lack of data but the graphics limitations of the CAD systems Crew Chief interfaced to. NASA Ames Research Center has developed a vision model which accounts for lighting.

[5] See Buchholz (1986).

Multi-person tasks. A large number of maintenance tasks require more than one person work at the same time, especially when heavy objects are moved. Therefore, to accurately estimate strength and accessibility requirements, at least two different man-models need to be able to work together.

Expand Human Factors Criteria

Personnel Factors. Task information presented through video display techniques should allow the perceptual and psychomotor ability requirements of maintenance tasks to be more accurately illustrated to users. These are natural, low-risk extensions of existing man-models. The addition of computer animation should allow activity and task sequences to be accurately modeled. If enough detail about human/machine interactions can be unveiled, it should also become possible to describe the cognitive demands of maintenance tasks.[6] The basic idea is to use computer graphics to discover what a task or, in the aggregate, a job will require in terms of basic human abilities or trained skills.

It should then become possible to produce accurate task ability profiles, to group tasks into logical jobs (job design), to develop job descriptions, and to establish valid personnel selection criteria. If this visual simulation could be extended across entire families of equipment or subsystems, the evaluation process could be extended into the realm of human resource forecasting, which is also known in the Air Force as Manpower, Personnel, and Training (MPT)[7]. The human resource implications of proposed designs are currently far removed from CAD/man-modeling technology. Yet this is where much of the support cost of Air Force systems is found. If we can use manpower and training resources more efficiently, enormous savings might be realized.

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[6]Taxonomies of human abilities relevant to this objective are described, for example, in the seminal work of Fleishman (1975), and Fleishman and Quaintance (1984).

[7]The Army's MANPRINT concept divides human-centered design into six domains: human factors, biomedical, safety, manpower, personnel, and training (MPT).

Training Factors. This advanced man-modeling technology may support training in both information development and requirements analyses. On the information side, stabilized design drawings could be ported from the workstation to the technical manual and training development activities of Integrated Logistics Support (ILS).[8] These, in turn, could eventually be used to create accurate and up-to-date job guides or job performance aids (JPA) for maintenance people. Man-model graphics might even be videotaped and distributed for direct instructional use. These potential training uses are in consonance with new Computer-aided Acquisition Logistics Support (CALS) Department of Defense (DoD) objectives.[9]

On the training requirements side, graphics-based simulation could provide a better basis for training versus JPA trade-off decisions. Often, the human factors analyst must judge whether task performance should be supported by formal or on-the-job training. But the absence of visual evidence about the task requirements has often made these judgments unduly subjective and haphazard. The objectivity and reliability of these judgments can only increase as graphics technology matures. The Instructional System Development (ISD) process can begin earlier using more accurate and complete task data. If man-modeling technology could help identify training issues earlier and more accurately, more training options might be considered and fewer training requirements would be missed.

Achieving these advancements in task analysis technology will require advances in the following two key areas:

1. Knowledge capture: New ways of marshalling relevant data from the scientific literature, handbooks and guides, HF and MPT data bases, and maintenance data sources are needed. Such data would be useful in

[8] ILS is the formalized process for integrating logistics into system engineering. The LSAR is the primary vehicle for ILS implementation.

[9] CALS will stimulate the conversion of paper-based equipment support data to digital format and the creation of standardized data exchange protocols, including graphics.

"instrumenting" tasks for direct visual simulation. They would also be useful in benchmarking physical, psychological, and performance requirements in support of task analysis for new equipment. The principal barrier to enhanced and expanded task analysis during equipment design is task detail.

To overcome this barrier, we will need to learn how to make better use of knowledge about human performance on existing systems in analyzing performance requirements for new ones. This will require new applications of comparison-based logic to identify analogous baseline cases. Data base technology will also be needed to bring together applicable information contained in diverse data bases.[10] This is a high-risk but high-payoff aspect of the proposed development.

2. Computer graphics technology: Animated representations of the human interacting with equipment and the work environment is expected to contribute heavily to this objective.[11] Technology for composing and displaying a complete maintenance task, or sequences of tasks, will permit broader estimation of physical and non-physical aspects of task and job requirements than current methods permit. The basic idea is to use computer technology to help create the information needed for task analysis. The information will support the analyst who must make judgments about task performance requirements.

Create Human Factors Workstation

The objective is to provide a versatile platform for the development, demonstration, and transition of advanced man-modeling and human factors analysis technology. This workstation will interface with CAD and LSAR systems. Access to external human performance data bases will also be provided. An "open" workstation architecture will allow new or

[10] See Boff (1987) on use and non-use of human performance data in human/machine design.

[11] Animation technology in support of task analysis is carried forward by Badler and his associates. See Badler (1989); Badler, Korein, Radick, and Brotman (1985); and Phillips and Badler (1988).

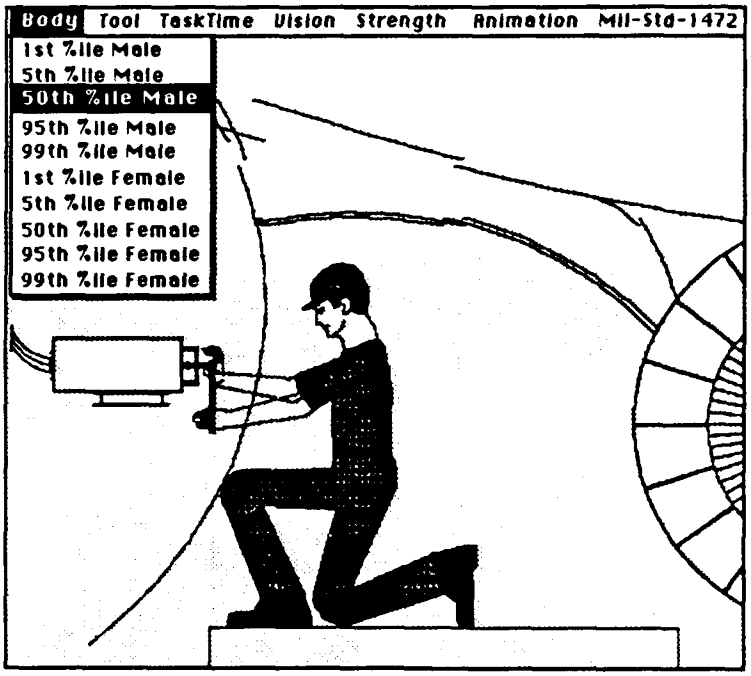

Figure 3. Advanced Man-model Display Screen

improved analysis models to be readily incorporated in modular fashion and support a strategy of incremental test and transition of new technology resulting from the research.

The workstation will house a man-model program, analytic tools, and interface software. It may also contain certain human factors data bases internally. The DoD human engineering standard (MIL-STD-1472) and the AFHRL Occupational Research Data Bank (ORDB) are examples of relevant data bases that will soon exist in electronic versions. These and other data bases may be accessible within the human factors workstation for use in task simulation and task analysis. The workstation will be used to generate animated, three-dimensional depictions of maintenance tasks. User-friendly menus and other software devices will aid the analyst in performing task analyses. The task analysis will be aimed at describing task and, if possible, job ability requirements. These procedures will be implemented using an appropriate taxonomy of human abilities.

Task information not amenable to or not needed for creation of visual task displays will be provided through "pop up" menus or other means to aid the task analysis. Figure 3 shows a notional screen for the

human factors workstation. The basic idea is to discover and to make fuller use of any information that may be applicable to proposed tasks to support a fuller task analysis during design.

Producing LSAR Information

As noted, the man-model workstation output will be used to populate LSAR data bases. The workstation should act as a sort of analytic node in a network linking CAD, which houses equipment design information, and LSAR, which houses the products of design analysis relevant to human resource requirements. These LSA products appear primarily in the form of task description and task analysis information.

Maintenance task analysis portions of LSAR (the C & D Records) would become populated with data created through the analysis process envisioned for this research. Created early and accurately, as they seldom are now, these LSAR data bases would form the principal input for system-level human resource aggregation and trade-off analyses. MPT and other "downstream" analyses, which are currently far removed from design engineering, could be linked in this way.

Develop Design-relevant Evaluation Criteria

The objective is to move the human factors assessment from a merely descriptive level (i.e.,"Something might be wrong.") to a prescriptive level (i.e.,"Something is wrong and here's how it can be righted."). This requires that measurable design goals or constraints be established and then monitored within the evaluation process. It also requires the specification of ameliorative measures that can overcome identified design deficiencies and/or enhance the role of the human in operating and maintaining weapon systems. These design prescriptive criteria will be implemented within the HF workstation in the form of an analyst's aid.

Some aspects of Air Force maintenance require complex reasoning skills and related cognitive abilities. Seen most vividly in equipment

packaged with automated diagnostic or troubleshooting aids, these devices often require the technician to monitor multiple data inputs and outputs at the same time. Such cognitively demanding information-processing tasks are likely to become more common in maintenance. Indeed, for at least some maintenance functions, the cognitive demands of maintenance work are apt to become more important than the physical demands (Binkin, 1986). Consequently, methods for simulating equipment operations that permit elucidation and perhaps training of underlying mental abilities will become very useful additions to human-modeling technology.

If budget decreases continue, the Air Force will need to reutilize systems through modification more often than develop new ones. Therefore, man-modeling technologies that can help "reverse engineer" existing systems will be increasingly valuable. And since a wider range of maintenance support options will need to be explored, the results from this research will have to be applicable to different maintenance environments. If this is done effectively, industrial repair processes in Air Force depots may benefit from this technology as much as flightline maintenance.

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